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A Review of Grid Requirements for Wind Farm in Denmark and China

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Abstract

Large integration of wind power in modern power systems sets new challenges in power system operation raising serious concerns on issues related to dynamic security, stability and reliability of the system. In addition to this, replacement of conventional power plants by wind power plants of similar size increases the risk of system failures. Nowadays, these new challenges in the power systems operation have resulted in continuous revision of the grid codes for wind power plants by the system operators in order to facilitate high penetration levels of wind power in a secure and reliable way. This paper presents an overview of the main technical issues related to the interconnection of large wind power into the grid as well as the main requirements adopted by the system operators in modern grid codes in order to allow large integration of wind power into the power system while ensuring the security and the reliability of the power system. Emphasis in the paper is on the grid requirements in Denmark and China regarding regulation of active power, regulation of reactive power and low voltage ride through capability.

1. Introduction

Up to 10 years ago, the wind power plants were not required to support the grid and were allowed to disconnect from the grid during grid disturbances [1]. However, nowadays the large integration of wind power in modern power systems and the replacement of conventional power plants by wind power plants impose new challenges for the power system operation, raising concerns about its dynamic security and reliability. Following these changes in the power systems over the last years, revised grid codes have been proposed by system operators in order to facilitate high penetration levels of wind power into power systems in a secure and reliable way [2].

The numbers of medium and large sized wind power plants have increased in the transmission system over the last years. They have become an important contributor to the power generation in many countries like Denmark, China, USA, Germany and Spain. For example in 2011, the installed wind capacity in China, US and Germany has been 62.7 GW, 46.9 GW and 29 GW respectively [3-4]. As a pioneer in the integration of wind power as well in the research and development of wind turbine technologies and control, Denmark is a good example for the newcomers into wind power. Today more than 20% of the power in Denmark is coming from the wind and the target is to reach 50 % share of wind power in 2025 [5].

The high integration of wind power in Danish power system obliges the transmission system operator (TSO) to continuously revise the grid codes for wind farms for a reliable operation of the power system [6]. According to [7], over the last few years the Chinese wind power sector has also been expanding with unprecedented rates of growth. Installed capacity of wind power in China at the moment is 62.7GW and the target is to reach 200 GW power from wind by 2020 and 400GW by 2030.

Nowadays the large integration of wind power into the Chinese power system is also arising more and more negative impacts on the power system security and reliability. For example, in China, some of the best resources of wind power are located far away from the load centers and the wind power plants are connected to weak points on the grid via long ac transmission lines [8]. These issues are leading to significant challenges for system operation like voltage control, reactive power management and low voltage ride through (LVRT). The grid operators in China have revised the grid codes over the last few years to accommodate large integration of wind power in Chinese power system.

The goal of this paper is to present and compare the main grid connection requirements for wind power plants in Denmark and China. The paper provides an insight into the main technical challenges for the power system due to the large integration of wind power into the grid as well as the way how the Transmission System Operators (TSOs) in Denmark and China are adopting the grid codes to integrate large amount of wind in the system without risking the security and reliability of the power system. This study is based on the grid codes issued at the moment by the Danish [9, 12] and the Chinese TSOs [10].

The paper addresses the grid requirements imposed in Denmark and China regarding regulation of active power, regulation of reactive power and LVRT capability. First basic definitions and terminologies are addressed and then specific requirements for both countries are discussed and compared.

2. Frequency/Active power regulation

Frequency and active power regulation services are typically needed during trips of power plants (electricity generation systems) or during changes of loads (consumers) in the power system. A balance between production of electricity and consumption of electricity must always be maintained in a power system. A change in this balance alters the system frequency and if this violates a strictly predefined frequency range it can threaten the stability and thus the security of the power system. Steady state frequency is an indication that the generation and the consumption are in balance.

Two types of reserve services are required to cope with the frequency deviation in a power system, namely spinning reserve and supplementary reserve. A power system should always have excess rotating capacity in order to be able to compensate for trips of large power plants. The spinning reserve is defined as the difference between the available generation capacity and the generating power output from power plants at the moment. It acts instantaneously after the trip of a large generator, as the rotating mass of the spinning plant tries to keep the frequency of the system constant. The spinning plant should be able to compensate for the loss of power by increasing its output immediately. A power system should also have supplementary reserve power plants, which can be brought into operation within 10 minutes and fully available within 30 minutes.

Frequency regulation is typically performed through the primary frequency control and secondary frequency control functions. Primary frequency control is the power control of a plant regulator, which has a response time within 30 seconds. This control function limits the frequency deviation due to sudden change in power unbalance and is performed by speed governors. Secondary control or automatic generation control restores the frequency back to its nominal value within 15 minutes, by adjusting the set points of the generators.

The generating units in a power system are designed to operate within a fixed frequency margin. The grid codes specify the frequency ranges and the duration for which the generating plants shall continue to operate with or without change in their output. As the operation outside these limits might damage the generating plants, the relays are typically designed to trip the generating plants during frequency deviation. The Danish TSO allows the wind power plants to continuously operate when grid frequency is in range of 49.5 Hz to 50.5 Hz [9]. In case when the frequency drops from 49.5 Hz to 47.5 Hz or rises from 50.5 Hz to 51 Hz, the operation is limited to 30 minutes. According to the Danish grid codes the wind power plant can operate for 3 min for grid frequency between 51 Hz and 53 Hz.

Similarly to the Danish grid codes, the Chinese TSO requires the wind power plants to operate continuously as long as the grid frequency is between 49.5 Hz to 50.5 Hz [10]. However, the Chinese TSO requires the wind plants to limit the operating time to 10min when grid frequency drops from 49.5 Hz to 48 Hz and to only operate for 2 minutes when grid frequency increases from 50.5 Hz and 51 Hz. In case when the grid frequency increases from 51 Hz, the wind plants shall limit their output power with the order of the dispatching company. In case when the grid frequency is below 48 Hz, the wind plants shall continue to operate according to their permissible level.

Each wind power plant connected to Danish power system has to cover several regulating functions to control its output power. The regulating functions depend on conditions of the grid and wind. This is to ensure that various regulating and constraint functions do not interfere with each other. The regulating functions imposed by the Danish TSO [9] are listed in a priority order in the following

System protection: During overloading in the grid, system protection function regulates the active power from wind power plant to power systems acceptable level. This regulating function contributes to avoid system collapse in case of any unforeseen incidents. The down regulation in wind power starts when system protection signal is activated and continues till the termination of external signal. It shall be possible to down regulate the wind power from full load to stop in a maximum of 30 sec. The system protection regulation is shown in the Figure 1.

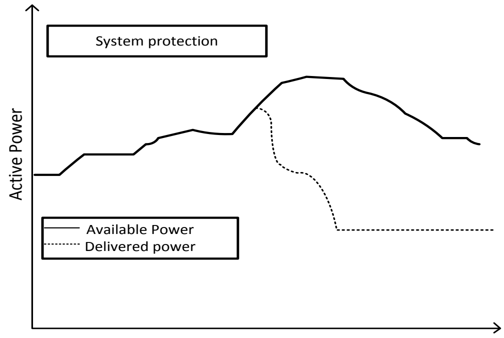

Figure 1: System Protection – source [9]

Frequency control: The automatic frequency regulation shall change the output power of the wind power plant to restore the normal frequency in case of deviation. Figure 2 shows two types of frequency control: the frequency control function shown by full drawn line can only make downward regulation of active power when frequency increases from the nominal value, whereas the control function shown by dotted line can make both upward and downward regulation. The upward regulation depends on the availability of active power when frequency drops than nominal value. The wind turbine when producing less than 20% of its rated power shall trip if it cannot down regulate its power with continued high frequency. The setting parameters for frequency control function are described in [9].

Stop regulation: Stop regulation function limits the active power output to current value and do not increase its production with the wind speed. On cancellation of 'stop regulation' function, the power output shall return to applicable power with an adjustable gradient.

Balance regulation: The power production from wind power plant is adjusted to balance the generation and consumption of active power in grid. The active power output from wind power plant is regulated up and down (±MW) with a desired power gradient (MW/min). The balance regulating function for wind power plant is shown in the Figure 3.

Power gradient constraint: This constraint function limits the rate in wind turbine output power with respect to wind speed changes as the conventional power plants might not be able to change their output as fast as the wind speed is changing. The power gradient constraint does not exceed the maximum settings provided by the system operator. Power gradient constraint function is shown in Figure 4.

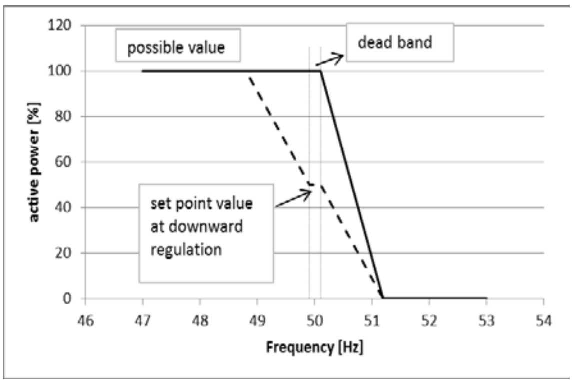

Figure 2: Frequency Control Regulation – source [9]

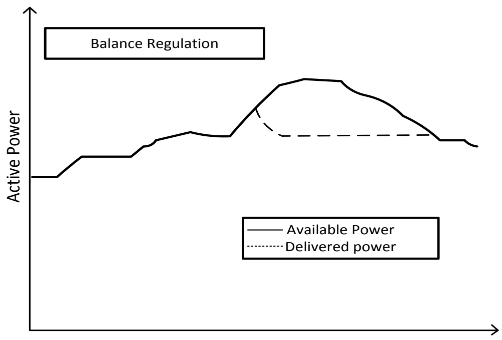

Figure 3: Balance Regulation- source [9]

Absolute production constraint: This regulating constraint limits the current power production of a wind power plant to random set MW value, when available power is in range of 20% to 100% of rated power. The maximum allowable deviation is ±5% of rated power at connection point. This regulating function shall not overload the grid. Absolute production constraint is shown in Figure 5.

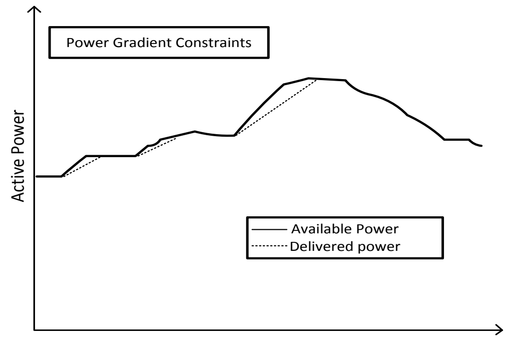

Figure 4: Power Gradient Constraint –source [9]

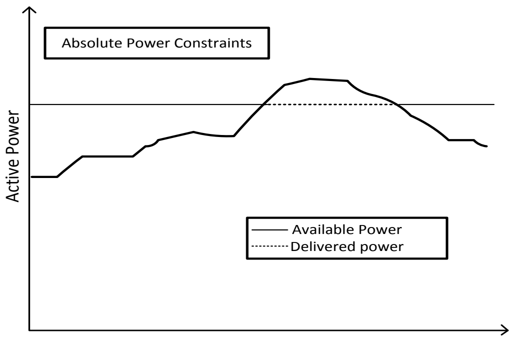

Figure 5: Absolute Power Constraint – source [9]

Delta production constraint: This constraint function limits the current power production of a wind power plant by a fixed amount, thereby setting aside reserve for handling critical power requirement. Delta production constraint function can take part in frequency control. It reduces the power fluctuations due to high wind thus reducing the need of spinning reserves. Delta production constraint function is exemplified in Figure 6.

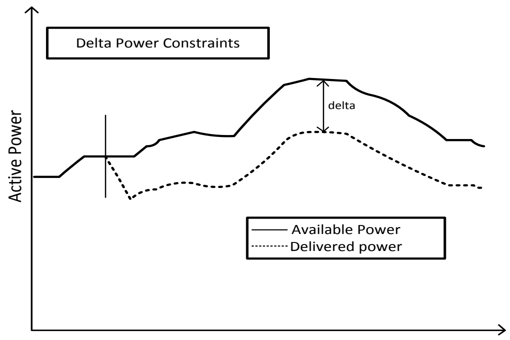

Figure 6: Delta Power Constraint – source [9]

The Chinese TSO sets also some technical requirements for the control of active power output from wind power plants [10]. For example, the wind power plants shall control the ramp rates of their output power. However, the ramp rate limit is not applicable during reduction in output power due to wind speed. The power ramp rate limits depend on the installed capacity of wind power plants and can be found in [10]. The wind power plants shall be able to control the active power for following emergency circumstances:

- Limits the active power when frequency increase from 50.5Hz
- Prevents transmission network overloading under power failure
- Shutdown the wind power plant during grid faults if wind power plant endangers the security and stability of power grid.

3. Voltage/reactive power regulation

Voltage and reactive power regulation services are very useful especially in areas that import electricity from remote power plants, as it is the case of China.

The reactive power transfer in a transmission line is controlled by the difference in the voltages magnitudes at the sending and the receiving end, while the difference in the voltage angles controls the active power transfer. To understand the relation between the voltage and reactive power, a simplified model of a power system with generator and load connected via transmission line is illustrated in Figure 7. The voltage gradient from sending end to receiving end is given in [11] as following:

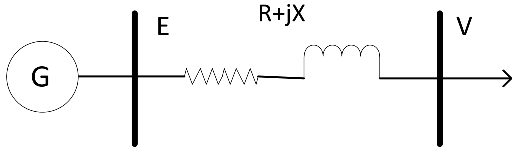

Figure 7: Simplified Power System model – source [11].

$$\begin{aligned}\Delta V &= E - V = (R + jX)\left(\frac{P - jQ}{E}\right) \\ &= \frac{RP + XQ}{E} + j\frac{XP - RQ}{E} \\ &= \Delta V_P + j\Delta V_Q \approx \Delta V_P = \frac{RP + XQ}{E}\end{aligned}$$

Where, E is the sending end voltage, V is the receiving end voltage, P and Q are the transmitted active and reactive power and R and X are the resistance and reactance of the power line.

As in most networks $X \gg R$, it means that there is a proportional relation between voltage gradient and reactive power, i.e. $\Delta V \propto Q$.Thus, voltage gradient along the line determines the reactive power transfer. A mismatch between the supply and demand of reactive power at the connection point alters the voltage at that point. During operational disturbances, the voltage at a faulted point on a line drops. The voltage drop boosts then the reactive power demand. This demand gets higher for the case of long transmission lines during faults or for wind farms connected to weak point on the grid.

For secure operation of the power system, the TSOs of different countries have placed regulations on large MW wind farms for controlling the voltage/reactive power at the connection point.

The TSO in Denmark allows the wind farm to operate continuously as long as the voltage at the connection point is between +5% and -10% of rated voltage. The operating time is limited to one hour with 10% reduction in power for voltage in range of +5% to +10% and -10% to 20%. According to [9], the wind farm shall be equipped with reactive power compensation ensuring that the reactive power is kept within the control band at connection point. The control band for reactive power is shown in Figure 8. In Denmark a wind farm controller shall ensure the following types of reactive power regulating functions for wind farm:

- desired reactive power supply at PCC
- desired voltage at the PCC by reactive regulation
- ensure minimum reactive power requirement

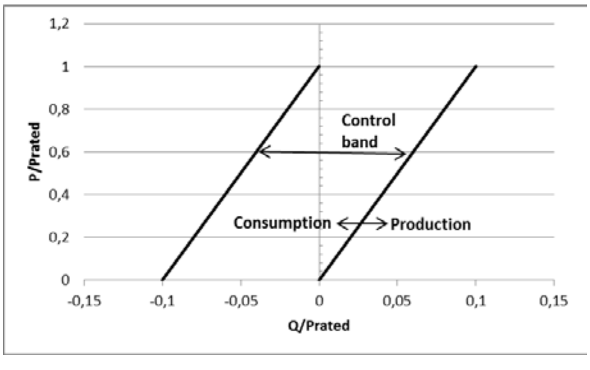

Figure 8: Reactive Power Control band –source [9]

The TSOs in China require wind power plants to operate normally when voltage at the connection point is ±10% of rated voltage. According to [10], the wind power plant shall be able to automatically control the voltage within +7% to -3% of rated voltage at the connection point. The voltage is controlled by regulating the reactive power or adjusting ratio of tap changing transfer. The wind power plants shall also maintain the power factor between 0.95 leading to 0.95 lagging and ensures the reactive power regulation capacity at any operational state. The high MW wind power plants shall compensate for losses in the transmission line at their rated output and also shall compensate for charging transmission line at no load.

These requirements imposed on wind farms by TSOs are very important for a country as China, due to the large import electricity from remote wind power plants. In China the best resources of wind power are located North and West far away from the load centers (East and South). Moreover they are connected to weak points on the grid via long ac transmission lines.

4. Low voltage ride through

Nowadays most of the grid codes require low voltage ride through (LVRT) capability from large wind power plants. This means that they have to remain connected to the network during faults.

During a grid fault, the voltage of the faulted phase falls due to low impedance on the transmission network. This causes a voltage depression, whose affect is propagated over wide areas until the fault is cleared. During voltage dip, the reactive power demand from induction generators is increased, this worsening even more the voltage depression during fault and the voltage recovery after the fault clearance. If the wind turbines are not able to withstand voltage depression it will start to trip. Disconnection of large share of wind power produces imbalance between generation and load and risks the system stability.

To secure the power system stability during and after a grid fault (i.e. short circuit), the power system will either require active power reserves that are available after the disconnection of the wind turbines or LVRT capability from wind power plants. The cost of the reserves is typically high as the generating plants have to operate below than their operating point. In [9], the Danish TSO specifies the LVRT capability for wind turbines and validates the wind turbine design in wind farm by ‘turbine test’. The ‘turbine test’ for wind farm stability is carried out via simulations, with Thevenin’s equivalent circuit shown in Figure 9 and with voltage profile shown in Figure 10. The three-phase short circuit is applied to the power grid when wind turbine is operating at rated power, nominal rotor speed and with full compensation.

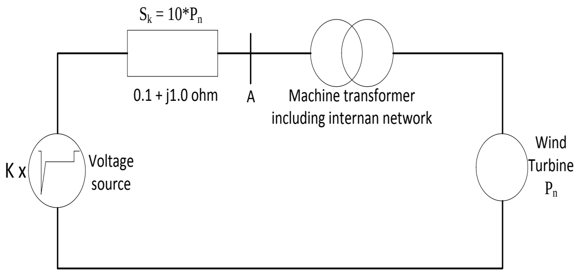

Figure 9: Thevenin's equivalent circuit

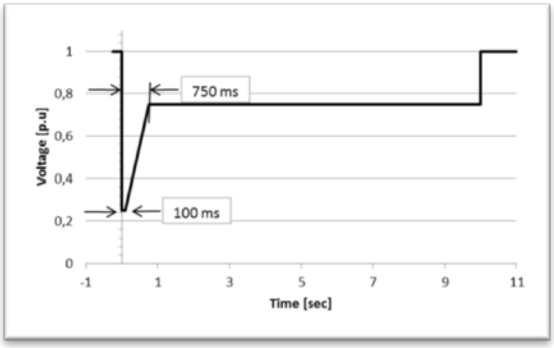

Figure 10: Voltage profile for Turbine test

The results obtained from simulations are successful when wind farms produce the rated power within 10 seconds after voltage reaches to 0.9 pu and the reactive power exchange as per grid code requirement. According to [9], in Denmark the wind farms shall also be able to withstand for asymmetrical and symmetrical faults without necessarily disconnection of wind turbines in the wind farm from the grid. Plant owner shall report the RMS value of current, voltage as well as active and reactive power changes during faults. During voltage dip, the wind farm regulation shall change from normal regulation to maximum voltage support taking into account that these regulations shall not cause voltage overshoot.

The LVRT capability of wind power plants required by Danish and Chinese TSOs are shown in Figure 11 and Figure 12, respectively. Figure 11 shows the voltage range for normal operation of wind power plant. Figure 11 also shows the voltage levels and the durations for which the wind power plant shall remain connected to the grid or it may/must be disconnected from the grid during fault. The voltage level and the maximum duration for which wind power plant must not disconnect from the network during fault are listed in Table 1.

Tabel 1: Disconnection criteria from Danish TSO during fault– source [12]

Disconnection criterion	Voltage [pu]	Maximum duration [s]
Under voltage	0.2	0.1
Under voltage	0.8	10
Under voltage	0.9	10..60
Over voltage 1	1.06	60
Over voltage 2	1.1	0.2

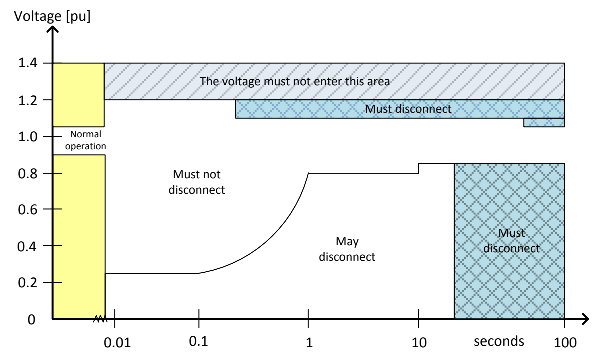

Figure 11: LVRT Requirement from Danish TSO – source [12]

Figure 12 shows that wind turbine in Chinese power system must remain connected to the network for voltage above than the curve and may be disconnected otherwise. The duration of the fault shall not increase from 625 ms and the voltage at connection point must not reduce from 0.2 pu. The voltage shall than rise linearly to 0.9 pu with in 3 sec for wind turbine to remain connected to the power system.

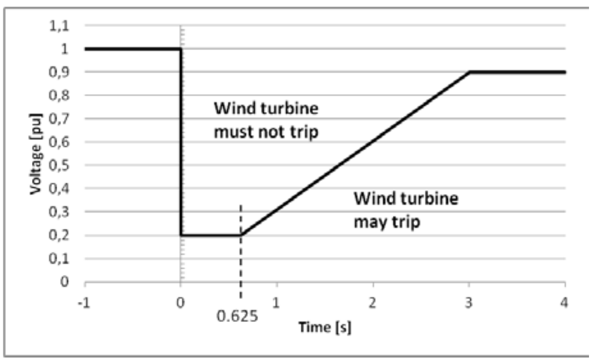

Figure 12: LVRT requirement from Chinese TSO – source [10]

Denmark has lower fault duration than China with only 100msec compared to 625msec. However, Denmark’s code requires the wind turbine to remain connected to the grid during successive faults.

5. Conclusion

A comparative review of the main requirements from TSOs in Denmark and China is made regarding the connection of large sized wind power plants to over 100kV transmission network. In both cases, the wind power plants must be able to provide with active and reactive control as well as with LVRT capability, similar to conventional power plants, in order to ensure secure and stable operation of the power system.

The Danish grid code defines different regulating functions for active and reactive power control and defines the necessary testing procedure for wind turbines in order to validate the FRT capability. On the other hand, the Chinese grid code focus on ramp rate control of active power output, voltage and/or reactive power control at the point of common connection and LVRT capability of the wind turbines. Chinese grid codes place special focus on voltage and reactive power regulation services in order to cope with numerous technical challenges encountered due to interconnections of large wind generating plants into weak grid sections through long transmission lines.

References

[1] J. Morren and Sjoerd W. H. de Haan ‘Ride through of wind turbines with doubly fed induction generator during a voltage dip’, IEEE transactions on energy conversion, vol. 20, no. 2, june 2005

[2] L. Holdsworth, I. Charalambous, J. Ekanayake and N. Jenkins, ‘Power system fault ride through capabilities of induction generator based wind turbines’, wind engineering volume 28, no. 4, pp 399, 2004

[3] EWEA, ‘Wind in power-2011, European 2011 statistics’, February 2012

[4] WWEA, ‘World wind energy report 2010’

[5] Andrew Smith, ‘Quantifying Exports and Minimizing Curtailment: From 20% to 50% Wind Penetration in Denmark’, BIEE 2010

[6] F. Iov, P. Sørensen, AD. Hansen, F. Blaabjerg, ‘Grid connection of active stall wind farms using a VSC based DC transmission system’, 2005 European Conference on Power Electronics and Applications, Pages: 10, ISBN: 9075815093, 07 August 2006

[7] Industrial wind action group, ‘http://www.windaction.org/news/31246’

[8] R. Piwko, N. Miller, J S Gasca, X. Yuan, R. Dai, J. Lyons, ‘Integrating Large Wind Farms into Weak Power Grids with Long Transmission Lines’, IEEE/PES Transmission and distribution conference & exhibition: Asia & Pacific Dalian, China, 2005

[9] ‘Grid connection of wind turbine to network with voltages above 100kV, Regulation TF 3.2.5’, Energinet.dk, December 2004

[10] ‘Technical Rule for Connecting Wind Farm into Power Network’, China Electric Power Research Institute, March 2009

[11] I. Martinez, J. Andreua, J. Martına, P. Ibanezb, J. Luis Villateb, H. Camblongc, ‘Connection requirements for wind farms: A survey on technical requirements and regulation’, Renewable and sustainable Energy Reviews 11 (2007) 1858-1872

[12] ‘Grid connection of wind turbine to network with voltages below 100kV, Regulation TF 3.2.6’, Energinet.dk, January 2003